

**ARRANGEMENT OF INTEGRATED CIRCUITS IN A MEMORY MODULE****Claim of Priority**

[0001] This application is a continuation of U.S. Patent Application No. 10/094,512, filed March 7, 2002, the disclosure of which is hereby incorporated in its entirety by reference herein.

**Related Applications**

[0002] This application is related to U.S. Patent Application No. 10/674,082 and to U.S. Patent Application No. 10/674,240, both filed on September 29, 2003, which are divisionals of U.S. Patent Application No. 10/094,512, filed March 7, 2002, and is related to U.S. Patent Application No. \_\_\_\_\_ (Attorney Docket No. NETL.001DV3) and U.S. Patent Application No. \_\_\_\_\_ (Attorney Docket No. NETL.001DV4), filed on January 27, 2004, which are also divisionals of U.S. Patent Application No. 10/094,512 filed March 7, 2002. This application is also related to U.S. Patent Application No. \_\_\_\_\_ (Attorney Docket No. NETL.001CP1), filed on January 29, 2004, which is a continuation-in-part of U.S. Patent Application No. 10/094,512, filed March 7, 2002.

**Background of the Invention****Field of the Invention**

[0004] The present invention relates to memory modules for use in computers. More specifically, the invention relates to the layout and organization of SDRAM memory modules to achieve 1-Gigabyte (i.e., 1,073,741,824 bytes) or more capacity using standard TSOP integrated circuits.

**Description of the Related Art**

[0005] The demand for high speed, high capacity memory modules for use in the computer industry has grown rapidly. The average base memory capacity of servers recently increased from 512 Megabytes to 1.2 Gigabytes. The cost of dynamic random access memory (DRAM) modules declined by more than 75%.

[0006] To successfully operate in a computer, a memory module must meet standard timing and interface requirements for the type of memory module intended for use in the particular computer. These requirements are defined in design specification documents that are published by either the original initiator of the standard (e.g., Intel or IBM) or a standards issuing body such as JEDEC (formerly, the Joint Electron Device Engineering Council). Among the most important design guidelines for memory module manufactures are those for PC SDRAM, PC133 SDRAM, and DDR SDRAM. The requirements documents also provide design guidelines which, if followed, will result in a memory module that meets the necessary timing requirements.

[0007] To meet the requirements defined in the SDRAM design guidelines and respond to consumer demand for higher capacity memory modules, manufacturers of memory modules have attempted to place a higher density of memory integrated circuits on boards that meet the 1.75" board height guideline found in the design specifications. Achieving the effective memory density on the printed circuit board has presented a substantial challenge to memory module manufacturers. High memory density on the memory module board has been achieved via the use of stacked integrated circuits and the use of more compact integrated circuit connector designs, such as micro-BGA (Ball Grid Array).

[0008] Use of non-standard integrated circuits, such as micro-BGA integrated circuits increases costs. Micro-BGA integrated circuits use a connection technique that places the connections for the integrated circuit between the body of the integrated circuit and the printed circuit board. Consequently, micro-BGA integrated circuits can be placed closer to one another on a board than can integrated circuits using the more prevalent TSOP (Thin Small Outline Package) packaging techniques. However, integrated circuits using micro-BGA connectors typically cost twice as much as comparable capacity TSOP integrated circuits.

[0009] Stacking a second layer of integrated circuits on top of the integrated circuits directly on the surface of the printed circuit board allows the manufacturer to double the memory density on the circuit board. However, the stacking of integrated circuits results in twice as much heat generation as with single layers of integrated circuits, with no corresponding increase in surface area. Consequently, memory modules using stacked

integrated circuits have substantial disadvantages over memory modules using a single layer of integrated circuits. Operating at higher temperatures increases the incidence of bit failure. Greater cooling capacity is needed to avoid the problems of high temperature operation. Thermal fatigue and physical failure of the connections between the circuit board and the integrated circuit can result from ongoing heating and cooling cycles.

## **Summary of the Invention**

**[0010]** A first aspect of the present invention is a memory module comprising a printed circuit board and a plurality of identical integrated circuits. The integrated circuits are mounted on one or both sides of the printed circuit board in first and second rows. The integrated circuits in the first row on a side are oriented in an opposite orientation from the integrated circuits in the second row on the same side. The orientation of the integrated circuits are indicated by an orientation indicia contained on each integrated circuit.

**[0011]** Another aspect of the present invention is a memory module comprising a printed circuit board. A plurality of identical integrated circuits are mounted in two rows on at least one side of the printed circuit board. The memory module also includes a control logic bus, a first register and a second register. The control logic bus is connected to the integrated circuits. The first register and the second register are connected to the control logic bus. Each row of integrated circuits is divided into a first lateral half and a second lateral half. The first register addresses the integrated circuits in the first lateral half of both rows. The second register addresses the integrated circuits in the second lateral half of both rows.

**[0012]** Another aspect of the present invention is a memory module comprising a printed circuit board. A plurality of identical integrated circuits are mounted in two rows on at least one side of the printed circuit board. The memory module includes a control logic bus, a first register and a second register. The control logic bus is connected to the integrated circuits. The first register and the second register are connected to the control logic bus. The first register accesses a first range of data bits and a second range of data bits. The second register accesses a third range of data bits and a fourth range of data bits. The first range of data bits and the second range of data bits are non-contiguous subsets of a data word. The third range of data bits and the fourth range of data bits are also non-contiguous subsets of a data word.

**[0013]** A further aspect of the present invention is a method for arranging integrated circuit locations on a printed circuit board. The method comprises placing locations for the integrated circuits in a first row and a second row onto at least one surface of

a printed circuit board. The integrated circuit locations in the second row are oriented 180 degrees relative to an orientation of the integrated circuit locations in the first row.

**[0014]** Another aspect of the present invention is a method for the manufacture of memory modules. The method comprises placing the locations for the integrated circuits on a printed circuit board in a first row and a second row on at least one side of the printed circuit board, and orienting the integrated circuit locations in the first row 180 degrees relative to the orientation of the integrated circuits in the second row. The method further comprises interconnecting the integrated circuit locations in a first half of the first row of integrated circuits and the first half of the second row of integrated circuits to a first register location, and interconnecting the integrated circuit locations in a second half of the first row of integrated circuit locations and the second half of the second row of integrated circuit locations to a second register location. The method also comprises placing identical integrated circuits at the integrated circuit locations in the printed circuit board.

**[0015]** Another aspect of the present invention is a 1-Gigabyte capacity memory module comprising 36 integrated circuits. The integrated circuits are 256-Megabit (i.e., 268,435,456 bits) SDRAM organized as 64 Meg by 4 bits (i.e., 67,108,864 addressed locations with 4 bits per location). The integrated circuits are in a Thin Small Outline Package (TSOP). The memory module has an approximate width of 5.25 inches (133.350 mm) and an approximate height of 2.05 inches (52.073 mm).

**[0016]** Another aspect of the present invention is a 2-Gigabyte capacity memory module comprises 36 integrated circuits. The integrated circuits are 512-Megabit (i.e., 536,870,912 bits) SDRAM organized as 128 Meg by 4 bits (i.e., 134,217,728 addressed locations with 4 bits per location). The integrated circuits are in a Thin Small Outline Package (TSOP). The memory module has an approximate width of 5.25 inches (133.350 mm) and an approximate height of 2.05 inches (52.073 mm).

#### **Brief Description of the Drawings**

**[0017]** The accompanying drawings are included to provide a further understanding of the present invention and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the present invention and, together with the description, serve to explain the principles of the invention.

[0018] FIGURE 1A illustrates a view of the primary side of a memory module in an embodiment of a PC133 SDRAM memory module

[0019] FIGURE 1B illustrates a view of the secondary side of the memory module of FIGURE 1A.

[0020] FIGURE 2A illustrates a view of the primary side of a memory module in an embodiment of a DDR SDRAM memory module.

[0021] FIGURE 2B illustrates a view of the secondary side of the memory module of FIGURE 2A.

[0022] FIGURE 3A is a block diagram of an embodiment of a PC 133 SDRAM memory module.

[0023] FIGURE 3B is an enlargement of one half of the block diagram of FIGURE 3A

[0024] FIGURE 4A illustrates a portion of the primary signal layer of a printed circuit board in an embodiment of a memory module.

[0025] FIGURE 4B illustrates a portion of the MID1 layer of a printed circuit board in an embodiment of a memory module.

[0026] FIGURE 4C illustrates a portion of the MID2 layer of a printed circuit board in an embodiment of a memory module.

### **Detailed Description of the Preferred Embodiment**

[0027] In the following description, reference is made to the accompanying drawings, which show, by way of illustration, specific embodiments in which the invention may be practiced. Numerous specific details of these embodiments are set forth in order to provide a thorough understanding of the invention. However, it will be obvious to one skilled in the art that the invention may be practiced without the specific details or with certain alternative components and methods to those described herein.

[0028] FIGURE 1A illustrates the primary side of an embodiment of a memory module 100. The module 100 comprises two rows of memory integrated circuits 102 mounted onto a printed circuit board 104. The memory module 100 meets the timing standards for and is compatible with JEDEC requirements for a PC133 SDRAM module, but departs from the design guidelines contained in the PC133 design specification. In particular,

the memory module 100 meets the timing and interface requirements of the PC133 standard notwithstanding the module 100 having a height (H) of approximately two inches. This height exceeds the 1.75" height guideline recommended in the PC133 Design Specification, but allows a single layer of conventional TSOP integrated circuits 102 to be placed in two rows on each side of the printed circuit board 104, thus avoiding the negative characteristics caused by stacking of integrated circuits and also avoiding the use of more expensive micro-BGA integrated circuits. The printed circuit board maintains a width (W) of 5.25" as defined in the PC133 Design Specification.

[0029] The memory module 100 is compatible with the timing requirements while using a greater printed circuit board height through the unique layout and arrangement of the integrated circuits 102 on the printed circuit board and the arrangement of integrated circuit interconnections. As illustrated in FIGURE 1A, the upper row of integrated circuits 102 (designated U1 through U10) are oriented in the opposite direction from the lower row of integrated circuits 102 (designated U11 through U18). FIGURE 1B illustrates the second side of the embodiment of a memory module 100. The upper row of integrated circuits 102 (designated U24 through U33) on the second side of the printed circuit board 104 are placed in an orientation opposite that of the lower row of integrated circuits 102 (designated U34 through U41). The orientation of each integrated circuit 102 can be advantageously determined from an orientation indicia 106. For example in the illustrated embodiment, the orientation indicia is a small circular mark 106 on the surface of the integrated circuit 102.

[0030] The different orientations of the upper row of integrated circuits 102 and the lower row of integrated circuits 102 allow the traces on the signal layer of the memory module 100 to be placed such that the trace lengths to the data pins on the integrated circuits 102 in the first (upper) row have substantially the same length as the signal traces to the data pins on the integrated circuits 102 in the second (lower) row.

[0031] FIGURE 4A illustrates a portion of a primary signal layer 400 of the printed circuit board 104 of the embodiment of a memory module 100 illustrated in FIGURE 1A and 1B. FIGURE 4B illustrates a portion of a MID1 signal layer 430 of the printed circuit board 104 of the embodiment of a memory module illustrated in FIGURE 1A and 1B. Figure

4C illustrates a portion of a MID2 signal layer 460 of the embodiment of a memory module illustrated in FIGURE 1A and 1B.

[0032] The illustrated portion of the primary signal layer 400 connects to the integrated circuits 102 designated U1 and U11. A signal trace 404 to one of the data pins of the U1 integrated circuit is designed to have substantially the same length from the data pin of the U1 integrated circuit to the primary memory module connector 420 as the length of a signal trace 414 from the corresponding data pin in the U11 integrated circuit to the primary memory module connector 420. The signal trace 404 from the U1 integrated circuit to the primary memory module connector 420 and the signal trace 414 from the U11 integrated circuit to the primary memory module connector 420 each include a respective portion of signal trace located on the MID2 layer 460 of the printed circuit board 104, as illustrated in FIGURE 4C. Similarly, a signal trace 408 from a second data pin on the U1 integrated circuit to the primary memory module connector 420 is designed to be of substantially the same length as the length of a signal trace 418 from the corresponding pin on the U11 integrated circuit to the primary memory module connector 420. As illustrated in FIGURE 4C, the signal traces 408, 418 also include respective portions of the traces located on the MID2 layer 460 of the printed circuit board 104.

[0033] A signal trace 402 and a signal trace 406 from third and fourth data pins on the U1 integrated circuit to the primary memory module connector 420 are designed to be substantially the same lengths as the lengths of a signal trace 412 and a signal trace 416 from the corresponding data pins on the U11 integrated circuit to the primary memory module connector 420. As illustrated in FIGURE 4B, the signal traces 402, 406, 412, 416 include a portion of the signal trace located on the MID1 layer 430 of the printed circuit board 104.

[0034] As shown in FIGURE 1A, four signal traces 404, 408, 416, 418 include respective resistors 107 affixed to a first set of connection points 407 (FIGURE 4A) on the primary signal layer 400 of the printed circuit board 104. As further shown in FIGURE 1A, the four signal traces 402, 406, 418, 414 include respective resistors 109 (FIGURE 4A) affixed to a second set of connection points 409 on the primary signal layer 400 of the printed circuit board 104. The resistors 107, 109 complete the circuit paths from the integrated



circuit pins to the connector 420 and also provide impedance matching required in the JEDEC standards.

[0035] The substantially equal signal trace lengths are repeated for each pair of integrated circuit locations in the first and the second row. By reversing the orientation of the integrated circuits 102 from the first row to the second row, the portions of the signal traces on the primary signal layer 400 serving an integrated circuit in the first row have substantially the same lengths as the signal traces serving a corresponding integrated circuit in the second row. The overall lengths of the traces are configured to be substantially equal (to within 10% of the total trace length) by varying the lengths of the portions of the traces located on the MID1 layer 430 and the MID2 layer 460. In addition to the data signal trace lengths, the data mask trace lengths and the clock trace lengths advantageously are maintained to be substantially equal.

[0036] Unlike known memory module circuit board designs, the substantial equality of trace lengths is achieved without requiring the addition of repetitious back-and-forth (i.e., serpentine) trace portions to the signal traces of the physically closer integrated circuits 102 to equalize the trace lengths of the signal lines of the closer integrated circuits 102 with the trace lengths of the signal lines of the integrated circuits 102 that are located physically farther from a common signal trace connector area 420. Since printed circuit board 104 space is not consumed with serpentine signal traces, the signal traces are advantageously wider, and the spacing between signal traces is advantageously greater. The greater width and spacing of the signal traces advantageously results in decreased signal noise and interference. The absence of serpentine signal traces advantageously results in a memory module 100 that produces less radio frequency interference and is less susceptible to radio frequency interference.

[0037] The timing requirements for the memory module 100 are advantageously met through the use of a second level of symmetry in addition to the use of substantially equal trace lengths. As shown in the block diagram FIGURE 3A, the address signals to the integrated circuits 102 in the top and bottom row (integrated circuits designated U1 - U5, U24 - U28, U11 - U14, and U34 - U37) on one half of the memory module 100 are routed from a common register 302 via a set 303 of signal paths. The address signals to the

integrated circuits 102 on the second half of the memory module 100 (designated U6 - U10, U29 - U33, U15 - U18, and U38 - U41) are routed from a common register 304 via a second set 305 of signal paths. The use of the bilateral symmetry allows closer matching of timing performance for the signals from the integrated circuits 102, improves the timing performance, and provides greater performance timing margins than traditional design guidelines in which each integrated circuit in a row of integrated circuits 102 is connected to a single register. The operation of the memory module 100 is synchronized with an external clock signal (not shown) from a computer (not shown) by a clock generator circuit 309, which is discussed in more detail below in connection with Figure 3B.

[0038] FIGURE 3B illustrates a half 310 of the block diagram shown in FIGURE 3A. As shown in FIGURE 3B, the bilateral symmetry utilizes non-contiguous ranges of data bits for each addressing register. Rather than handling the bits in contiguous ranges such as bits 0-31 addressed in a first register and bits 32-63 addressed in a second register, as described in the JEDEC design guidelines, the first register 302 addresses data bits 0-15 (designated D0 through D15) and data bits 32-47 (designated D32 through D47). The second register 304 addresses the integrated circuits 102 on the second half of the board (not shown in FIGURE 3B), which store data bits 16-31 and bits 48-63. Each data bit (designated D0 through D63) and each check bit (designated CB0 through CB7) connects to the memory module connection interface 314 via a respective signal trace 311 which contains a respective resistive element 312. The resistive elements 312 in FIGURE 3B correspond to the resistors 107, 109 in FIGURE 1A. The physical layout of the signal traces 311 is illustrated in FIGURES 4A through 4C. Although the data word must be assembled from the bits addressed by both registers, the use of non-contiguous portions of the data word advantageously allows the use of a symmetric layout of the memory module 100 that complies with memory module timing requirements on a physically larger board than envisioned in the design guidelines. The use of bilateral symmetry in the board layout and the use of non-contiguous bit ranges is advantageously usable for larger data word lengths than the 64-bit word length given in this embodiment.

[0039] The operation of the memory integrated circuits U1-U18, U24-U41 and the operation of the common registers 302, 304 are controlled by a plurality of clock signals

PCK0-PCK9 from the clock generator circuit 309. The clock generator circuit 309 includes a phase locked loop (PLL) (not shown) that operates in a conventional manner to synchronize the clock signals with an input clock signal (CKIN) from the computer (not shown) or other system into which the memory module is inserted. Each of the clock signals PCK0-PCK8 is connected to four memory integrated circuits, and the clock signal PCK9 is connected to the common registers 302, 304. In the illustrated embodiment, the clock signals are connected to the memory integrated circuits and the common registers as follows (only the connections to the circuits shown in FIGURE 3B are illustrated):

|      |                            |                    |
|------|----------------------------|--------------------|
| PCK0 | U11, U12, U34, U35         | (D0-D3, D4-D7)     |
| PCK1 | U13, U14, U36, U37         | (D8-D11, D12-D15)  |
| PCK2 | U15, U16, U38, U39         | (D16-D19, D20-D23) |
| PCK3 | U17, U18, U40, U41         | (D24-D27, D28-D31) |
| PCK4 | U1, U2, U24, U25           | (D32-D35, D40-D43) |
| PCK5 | U3, U4, U26, U27           | (D36-D39, D44-D47) |
| PCK6 | U1, U2, U24, U25           | (D48-D51, D52-D55) |
| PCK7 | U9, U10, U32, U33          | (D56-D59, D60-D63) |
| PCK8 | U5, U6, U28, U29           | (CB0-CB3, CB4-CB7) |
| PCK9 | control registers 302, 304 |                    |

[0040] As shown in FIGURE 1B, the integrated circuits 102 are advantageously mounted on both sides of the printed circuit board 104. The mounting of integrated circuits 102 on both sides of the printed circuit board, and the use of bilateral symmetry of the signal traces on the printed circuit board advantageously permits the use of a larger printed circuit board and standard memory integrated circuits 102. The integrated circuits 102 used are advantageously commercially available 64 Meg by 4-bit (67,108,864 address locations with 4 bits per location) memory integrated circuits for a 1-Gigabyte capacity memory module 100 and are advantageously commercially available 128 Meg by 4-bit (134,217,728 addressed locations with 4 bits per location) memory integrated circuits for a 2-Gigabyte capacity memory module 100. Because of the location of the data pins of the integrated circuits 102, the four data pins of the integrated circuits 102 on the second side of the printed circuit board 104 are directly opposite the four data pins of the integrated circuits 102 on the first side of the printed circuit board. Thus, the data pins of the integrated circuit on the opposite side are serviced by the signal traces shown in FIGURE 4A using a via between the two sides for each signal trace.

[0041] An embodiment of a memory module 200 that is compatible with the timing requirements for Double Data Rate (DDR) SDRAM is shown in FIGURE 2A and FIGURE 2B. The DDR SDRAM module 200 comprises memory integrated circuits 202 utilizing standard TSOP packaging that are compatible with the JEDEC DDR timing requirements. The DDR SDRAM module 200 advantageously utilizes bilateral symmetry to achieve the timing requirements specified in the DDR SDRAM requirements on a board 204 having a height (H) of approximately 2 inches and a width (W) of 5.25 inches..

[0042] In FIGURES 2A and 2B, the integrated circuits 202 are oriented, as advantageously indicated by an orientation indicia 106, in opposite orientations in a first and a second row, respectively. The trace lengths of signal traces to the integrated circuits 202 in the first (upper) row are maintained to be substantially the same as the signal traces to integrated circuits 202 in the second (lower) row. The integrated circuits 202 mounted to a first half of the memory module 200 are routed to a first register 210 and the integrated circuits 202 mounted to a second half of the memory module 200 are routed to a second register 220. As with the PC133 SDRAM module 100, each data register stores non-contiguous portions of the data word.

[0043] Although the invention has been described in terms of certain preferred embodiments, other embodiments that are apparent to those of ordinary skill in the art, including embodiments which do not provide all of the features and advantages set forth herein, are also within the scope of this invention. Accordingly, the scope of the invention is defined by the claims that follow.